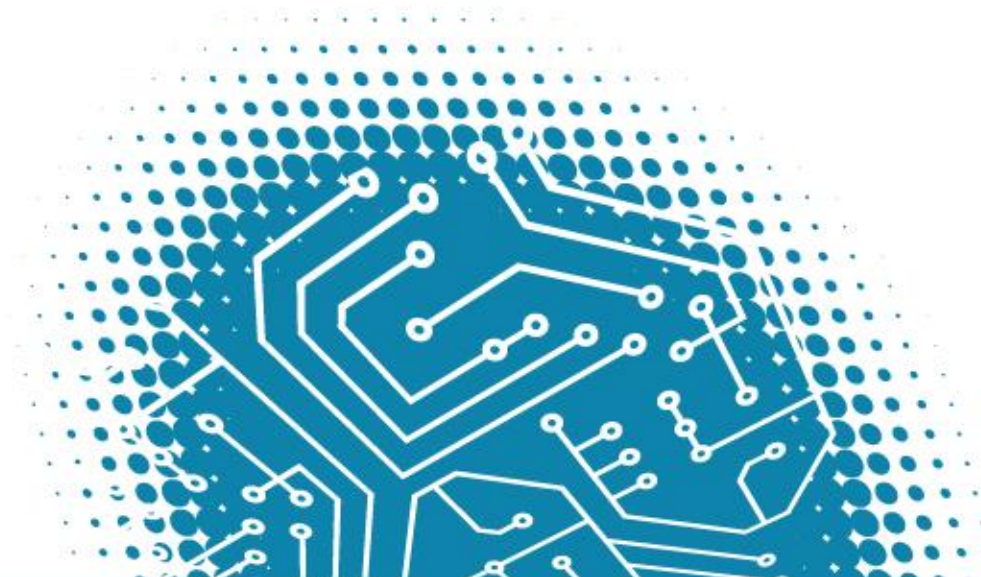


DESIGN STRATEGIES FOR ARM[®] SYSTEMS

An Avnet Design Summit

LOW POWER WIRELESS NETWORKS

Joe Tillison



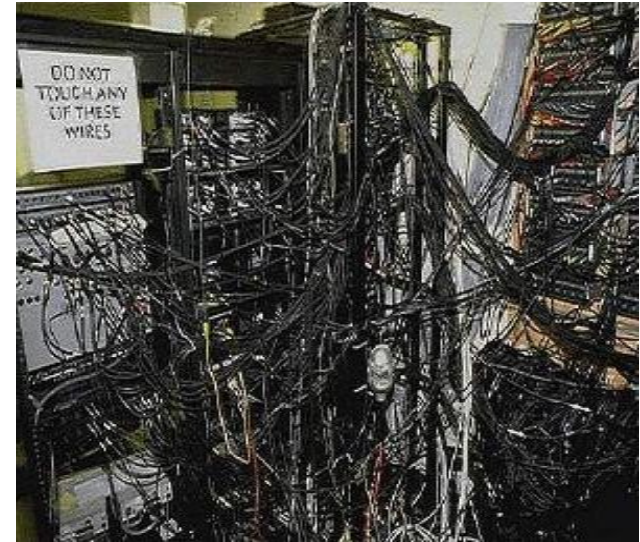
- » This presentation is:
 - » A scratch-the-surface introduction to basic concepts
 - » Terminology, protocols and applications
 - » A brief overview of the components of a wireless node
 - » Some discussion of wireless design considerations

- » This presentation is not:
 - » A deep-dive into intricacies of wireless protocols
 - » A deep-dive on wireless circuit design

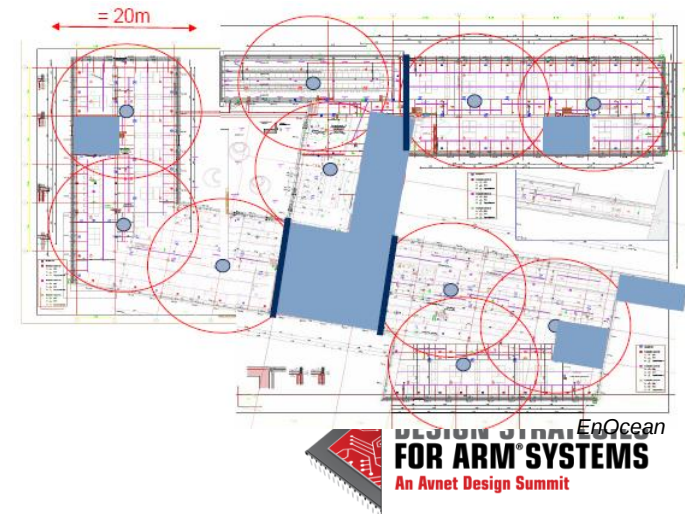
Why Wireless?

3

- » Cable replacement
 - » Costs of wiring
 - » Labor for installation
 - » maintenance
- » Expandability
 - » New nodes easily added
- » Reliability and Maintenance
 - » Self-healing
 - » Dead node detection
- » Where cabling isn't practical
 - » Mobile equipment
 - » Dangerous/harsh environments



Cambridge Consultants. Ltd.



Growing Markets / Applications

4



Process Automation



Access Control



Remote Monitoring



Decawave. Ltd.



Smart Energy



Home/Bldg Automation



Food/Water Quality



Asset Management



Lighting Controls



Remote Controls



Healthcare

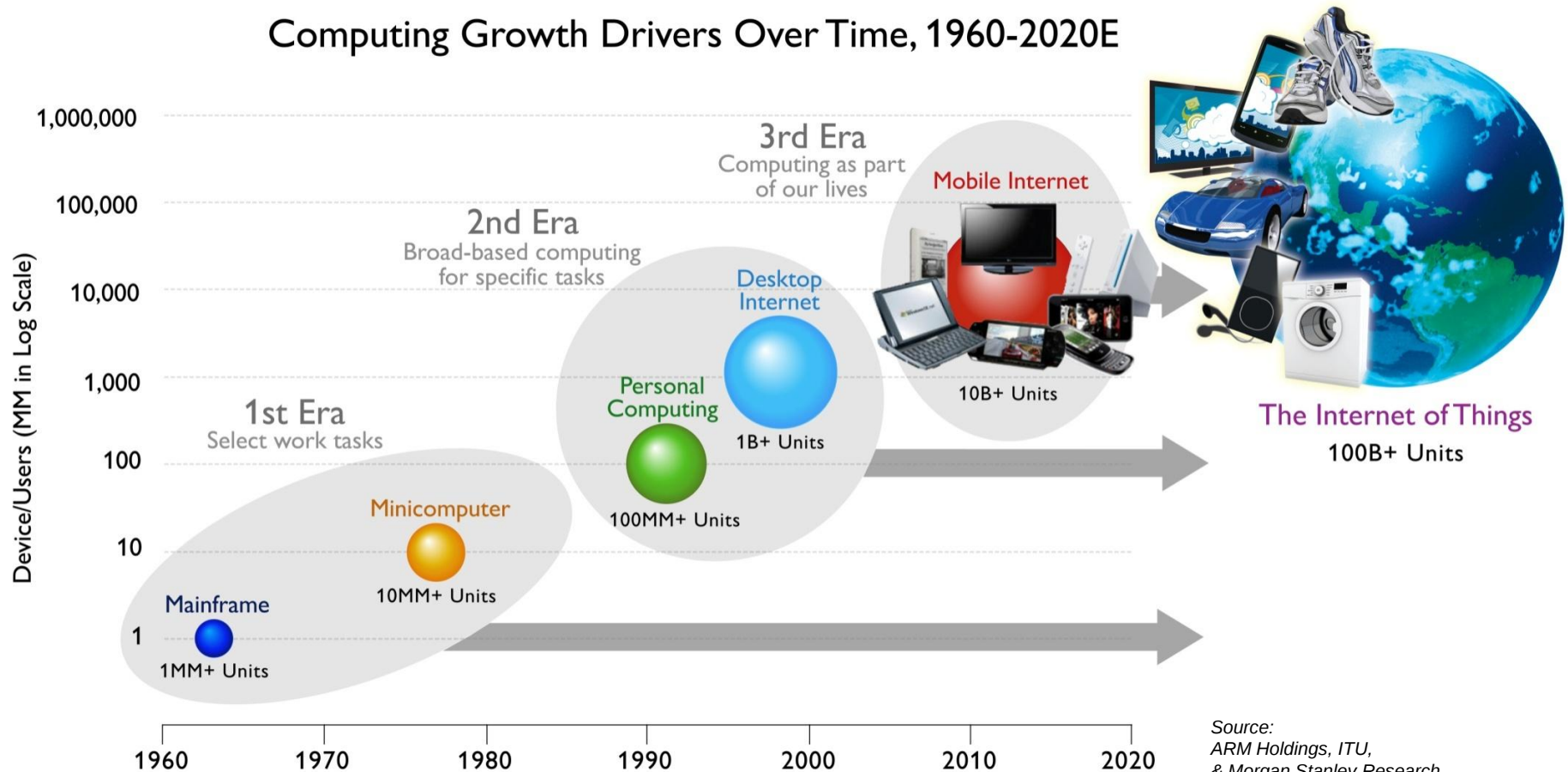


HVAC controls

Connectivity is Driving The Future

5

Computing Growth Drivers Over Time, 1960-2020E



Source:
ARM Holdings, ITU,
& Morgan Stanley Research

The “Internet of Things”

6

WPAN : Wireless Personal Area Network

BAN : Body Area Network

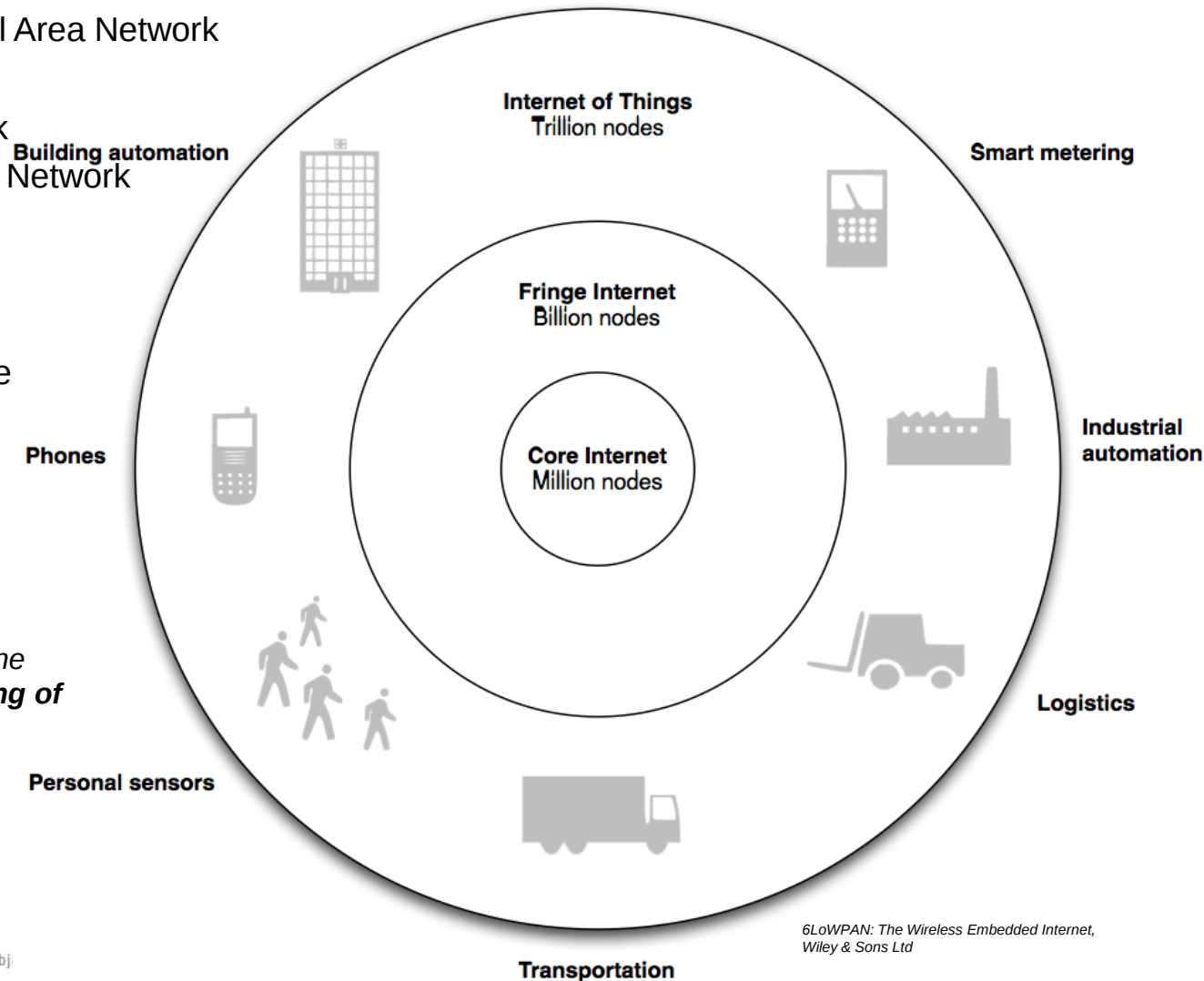
HAN : Home Area Network

NAN : Neighborhood Area Network

FAN: Field Area Network

WSN : Wireless Sensor
and Actuator Network

M2M : Machine to Machine

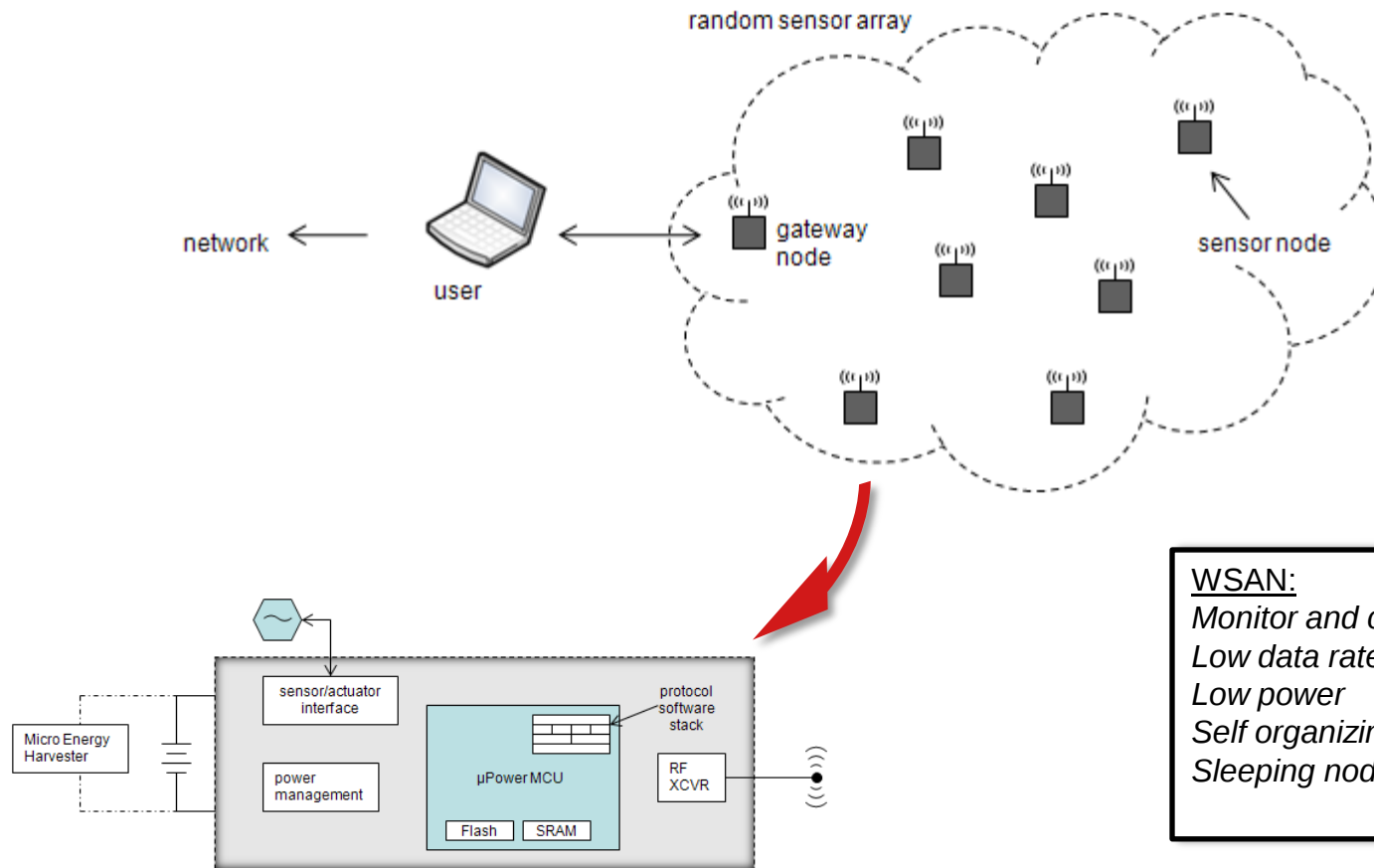


*“We are able to connect almost everybody now, Soon we will have the ability to **connect almost every thing of value.**”*

Paul Havingas, CTO, Ambient Systems

What is a Wireless Sensor Network?

7



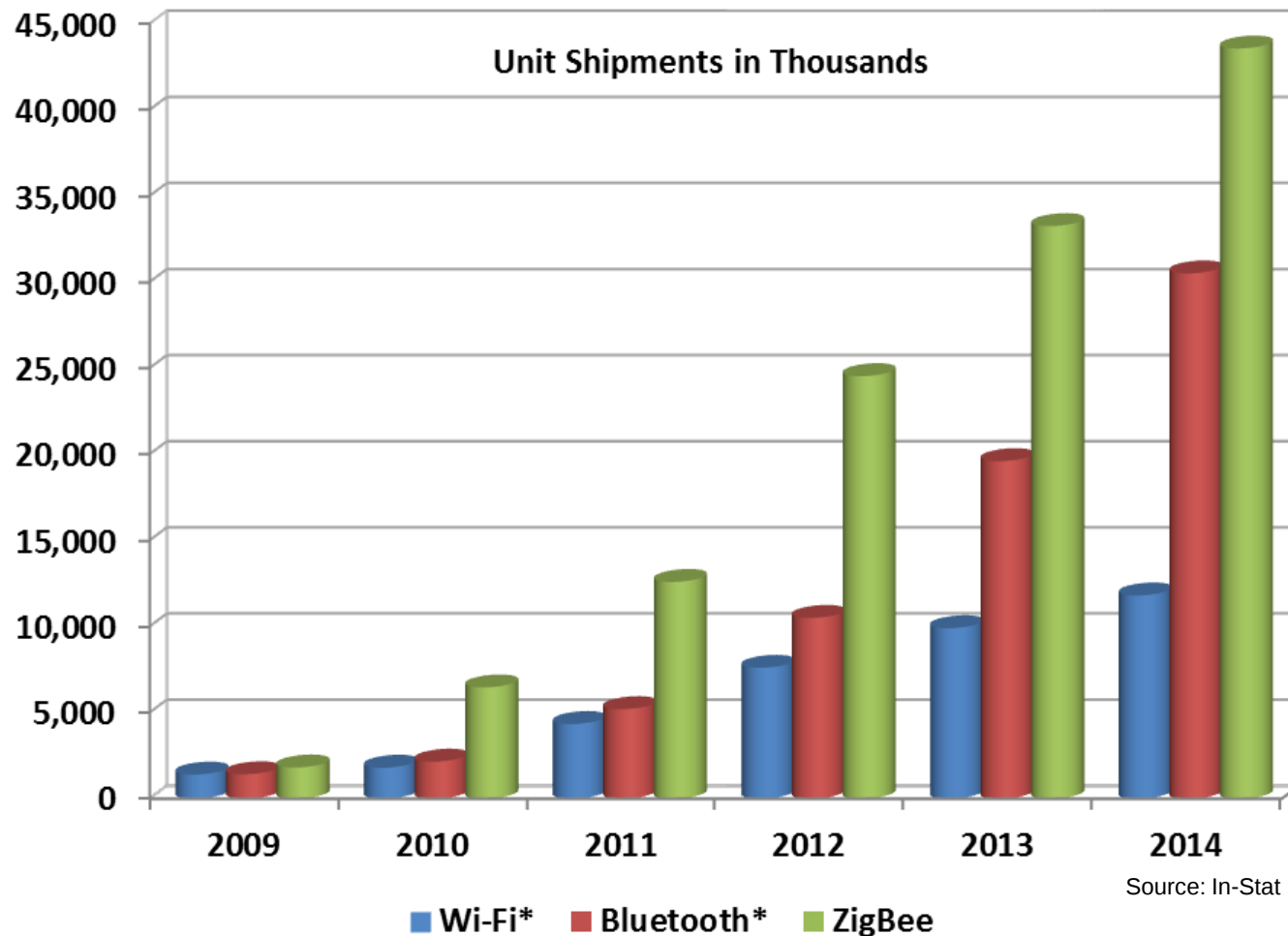
WSAN:
Monitor and control
Low data rate
Low power
Self organizing
Sleeping nodes

Popular Wireless Protocols

Wireless Technology	Version	Frequencies	Max Data Rate	Range*	Network Application	Max Power Permitted	Focus	Typical Applications
Wi-Fi	802.11a	5.0 GHz	54 Mbps	30m	WLAN	-	Data rates	Home Networking
	802.11b	2.4 GHz	11 Mbps	30m				
	802.11g	2.4 GHz	54 Mbps	30m				
	802.11n	2.4/5.0 GHz	200 Mbps	50m				
	Wi-Fi Direct	2.4/5.0 GHz	250 Mbps	-	WPAN	-	Peer-to-peer/ wire replacement	Consumer electronics (peer-to-peer)
ZigBee	802.15.4	868 MHz	20 Kbps	30m	WPAN	1W	Low cost Low power Low latency	Energy management Industrial control Consumer electronics
		915 MHz 2.4 GHz	40 Kbps 250 Kbps					
Bluetooth	Version 1.x	2.4GHz	1 Mbps	Class 1 - 100m	WPAN	Class 1 - 100 mW Class 2 - 2.5 mW Class 3 - 1 mW 0.01-0.5 mW	Peer-to-peer/ wire replacement	Handsets PC Peripherals
	Version 2.x	2.4GHz	3 Mbps	Class 2 - 10m				
	Version 3.0	2.4GHz	24 Mbps	Class 3 - 1m				
	Bluetooth LE	2.4 GHz	1 Mbps	-			Low power	Remote sensors

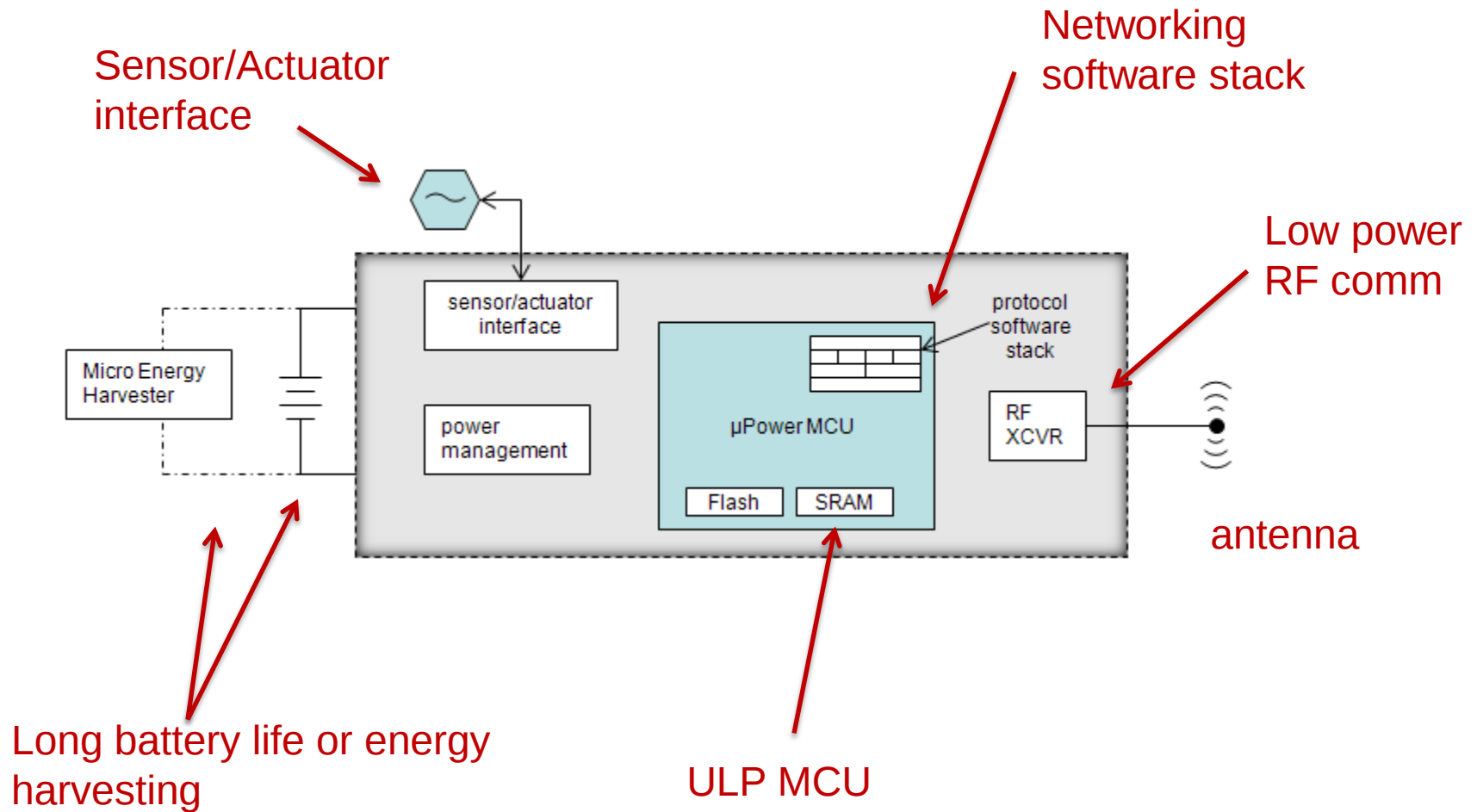
Source: In-Stat, 11/10

Wireless Device Shipments



Components of a Wireless Sensor/Actuator

10



11

Digital Carrier Modulation

12

$$s(t) = A(t) \cdot \cos(w(t) + \phi(t))$$

$A(t)$ $w(t)$ $\phi(t)$

Phase Shift Keying

PSK

BPSK (2-PSK)

QPSK (4-PSK)

16PSK

DPSK

Frequency Shift Keying

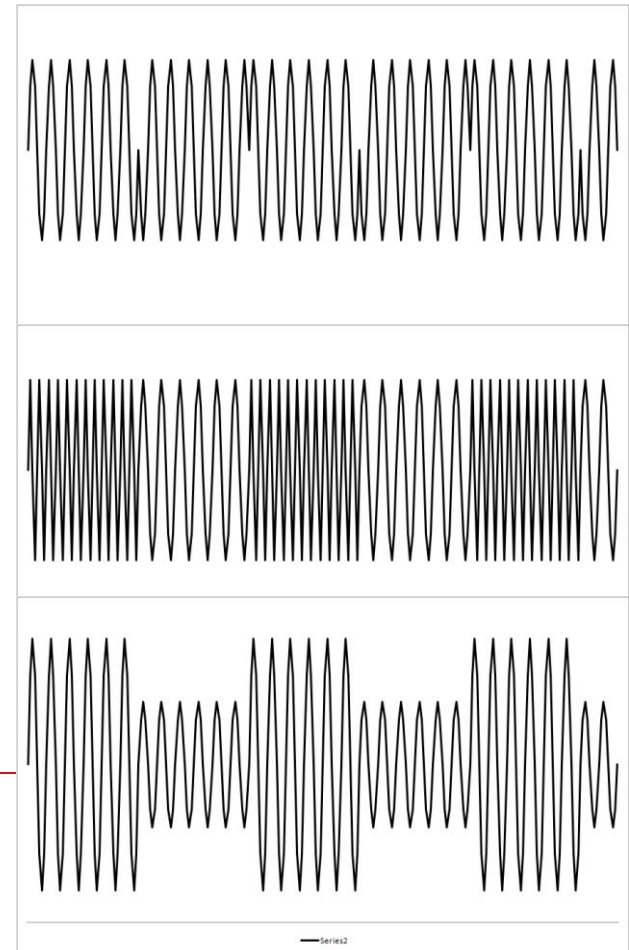
FSK

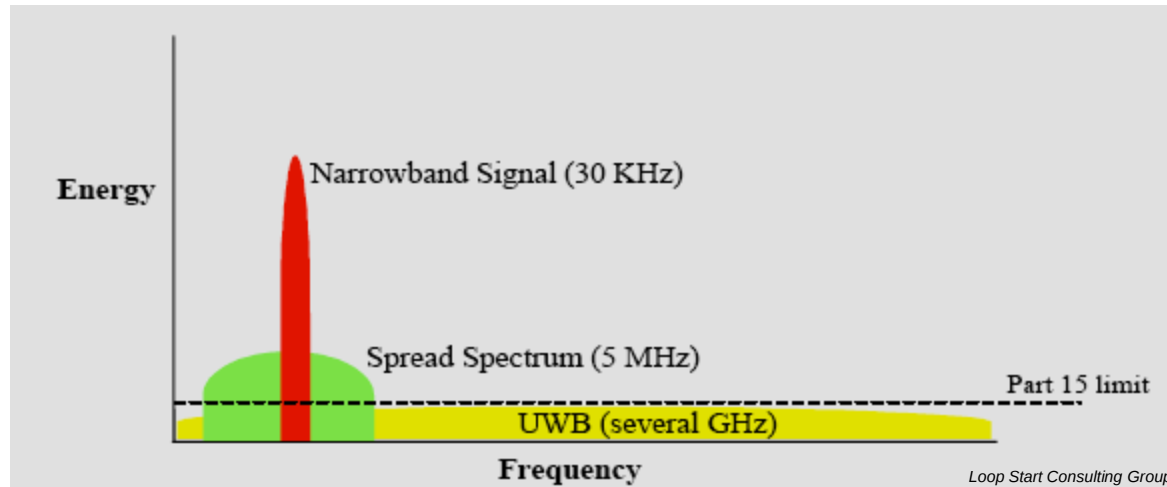
M-FSK

Amplitude Shift Keying

ASK

OOK



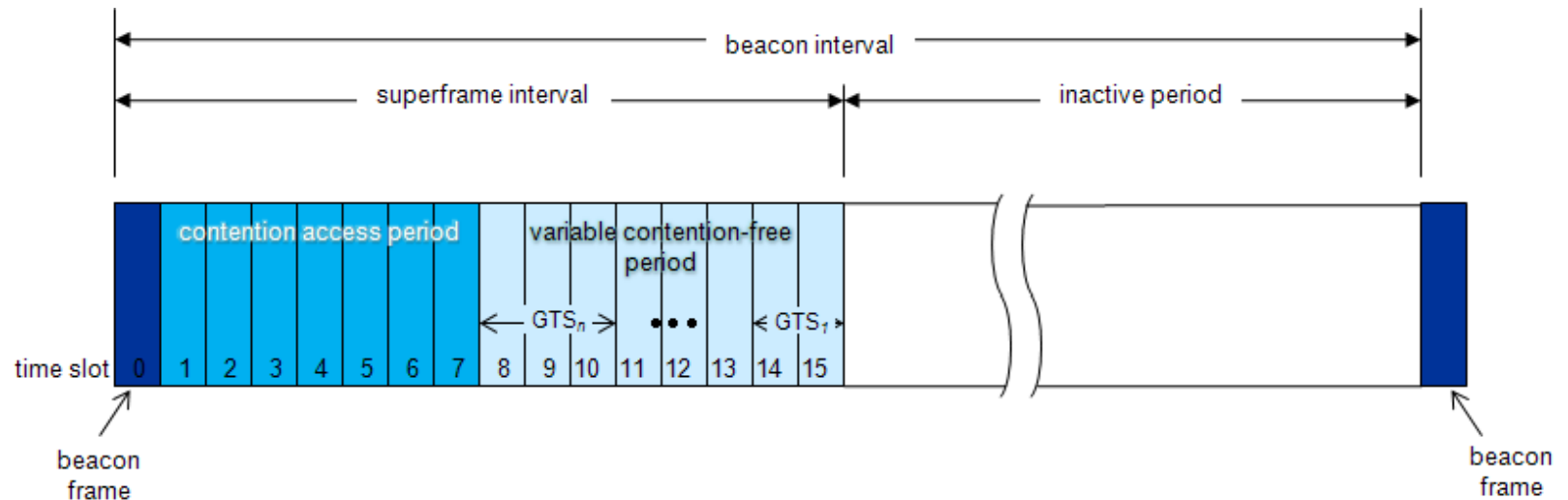
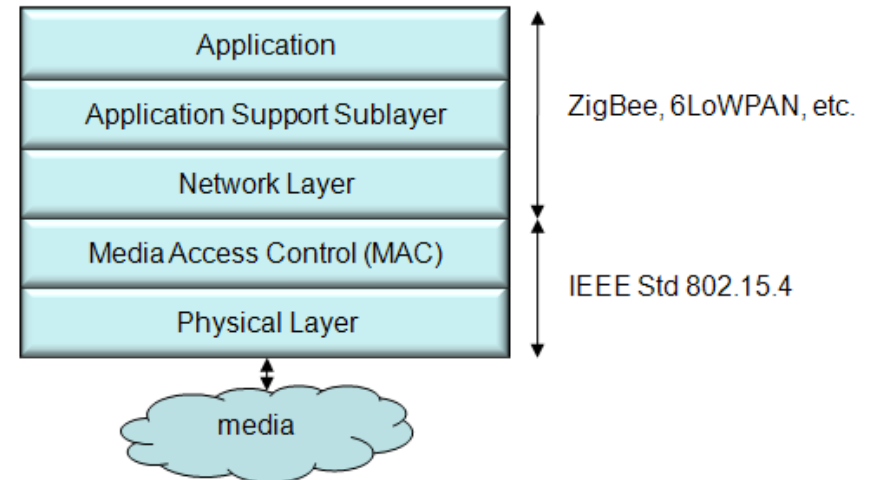


- » Frequency Hopping Spread Spectrum (FHSS)
- » Direct Sequence Spread Spectrum (DSSS)
- » Chirp Spread Spectrum (CSS)
 - » IEEE 802.15.4a

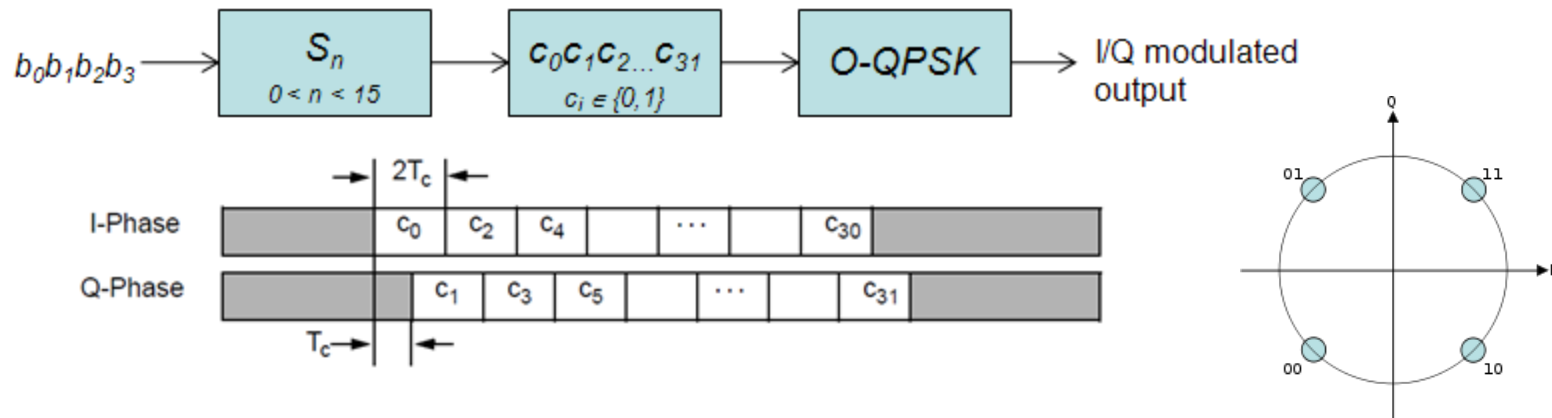
IEEE802.15.4 MAC

14

- » CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance
- » Up to 127 byte data packet with CRC
- » Fully acknowledged
- » Mesh, star or cluster tree topology
- » 16 or 64-bit addressing
- » Three roles: end device, coordinator, and PAN coordinator
- » Two devices types: FFD, RFD
- » 128-bit AES encryption link layer security
- » Two modes:
 - » Beaconless – pure CSMA
 - » Beaconed – superframe with reserved time slots



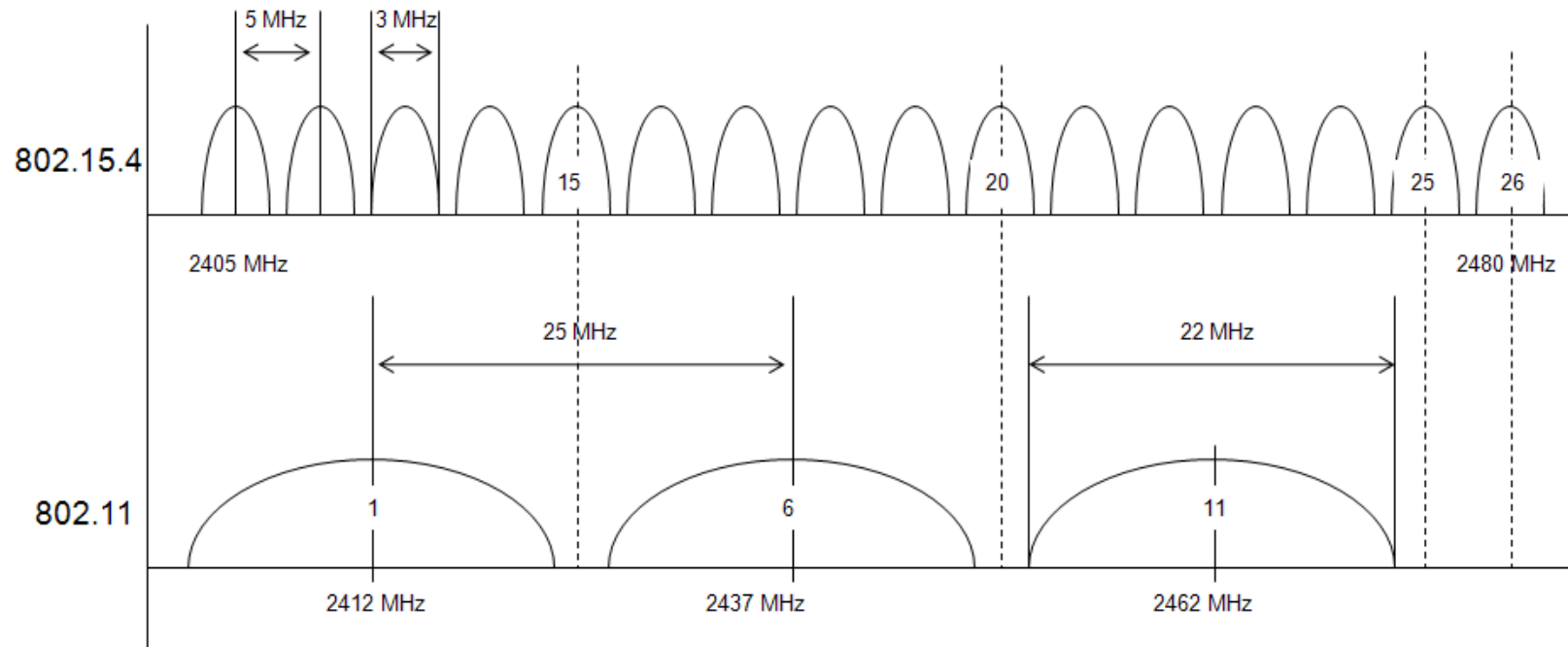
PHY (MHz)	Frequency Band (MHz)	Modulation	Channels	Channel spacing	Bit rate (kbps)	Symbol rate (ksymbol/s)	Symbols
868	868-868.6	BPSK	1	-	20	20	binary
868	868-868.6	ASK	1	-	250	12.5	20-bit PSSS
868	868-868.6	O-QPSK	1	-	100	25	16-ary orthogonal
915	902-928	BPSK	10	2MHz	40	40	binary
915	902-928	ASK	10	2MHz	250	50	5-bit PSSS
915	902-928	O-QPSK	10	2MHz	250	62.5	16-ary orthogonal
2450	2400-2483.5	O-QPSK	16	5MHz	250	62.5	16-ary orthogonal



2.45GHz PHY Direct Sequence Spread Spectrum Conversion

IEEE Std 802.15.4 and 802.11 Co-existence at 2.4 GHz

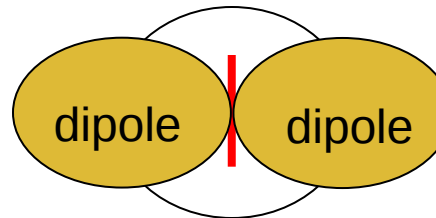
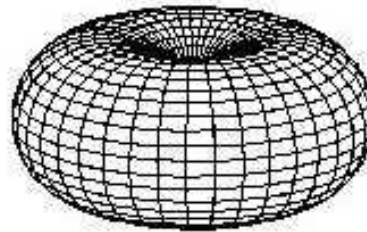
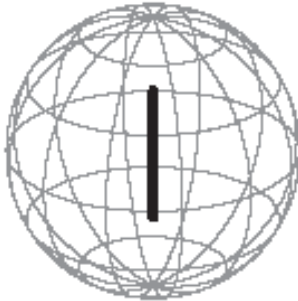
16



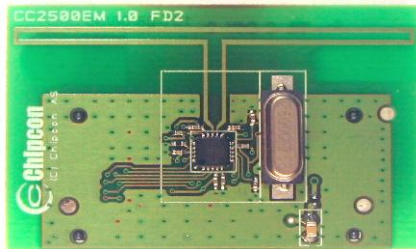
Antennas

17

Isotropic Antenna



Gain is referenced
to ideal isotropic antenna
 $0 \text{ dBd} = 2.14 \text{ dBi}$



TEXAS
INSTRUMENTS

PCB (dipole)



Chip/Puck



Whip



Custom Molded

Antenna datasheets

18

- » Frequency Range(s)
- » Radiation Pattern/Gain Plots
- » VSWR
- » Polarization
- » Feedpoint
- » Power Handling
- » PCB Layout

Specifications

Frequency Range (MHz)	824 – 894; 1850 – 1990
Peak Gain	0 dBi; +3 dBi
VSWR	< 3.0:1; < 3.0:1
Polarization	Linear
Power Handling	10 Watt cw
Feed Point Impedance	50 Ohms
Size	38.10 mm x 15.24 mm x 1.57 mm
Weight	< 2 g.
Mounting	Tab mounted with plated through holes. See page 2
Keep Out Area	See diagram on page 2



Antenna Solutions

824 – 894 & 1850 – 1990 MHz Dual Band Antenna (US Dual Band)

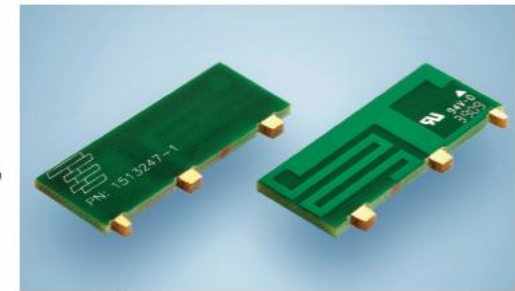
Part Number: 1513247-1

Product Facts

- Small and lightweight.
- RoHS compliant

Recommendations

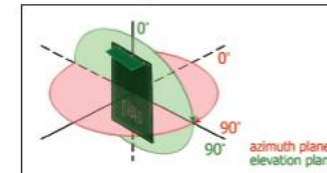
- Minimum or no matching circuits required.
- Bandwidth and performance is dependent on ground plane size. Suggested minimum ground plane length from the antenna feed is 100 mm.



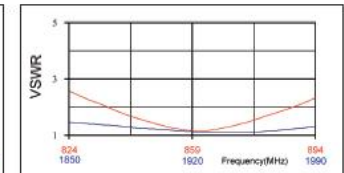
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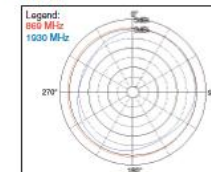
Test Orientation in Free Space



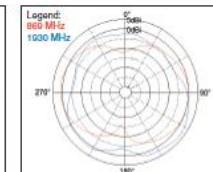
VSWR



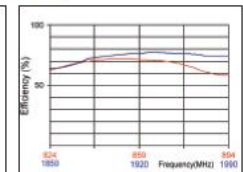
Azimuth



Elevation



Efficiency



Catalog 2-1773459-8
Revised 12-10

www.ti.com
http://www.antenna.ti.com

Dimensions are in inches and millimeters unless otherwise specified. Values in brackets are metric equivalents.

Dimensions are shown for reference purposes only. Specifications subject to change.

USA: 1-800-522-6732
Canada: 1-800-470-4425
Mexico: 01-800-723-8926
C. America: 52-55-1106-3808

South America: 55-11-2109-6000
Hong Kong: 852-2735-1628
Japan: 81-44-844-8013
UK: 44-3705-080-208

Friis Transmission Formula (free space, line-of-sight)

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

P_t, P_r = transmit or receive power (W)

G_t, G_r = gain of transmitting or receiving antenna

λ = wavelength = $3 \times 10^8 / f$

R = range (meters)

$$R = \frac{23.9}{f \text{ (MHz)}} \sqrt{\frac{P_t G_t G_r}{P_r}}$$

Example:

$P_t = 0 \text{ dBm} = 1\text{mW}$

$P_r = -90 \text{ dBm} = 1 \times 10^{-12} \text{ W}$

$G_t = G_r = 0 \text{ dBi} = 1$

$f = 2450 \text{ MHz}$

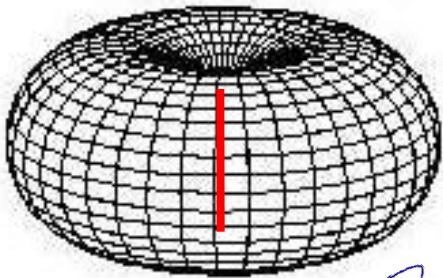
$\therefore R = 308 \text{ m}$

Online Friis calculator: <http://www.random-science-tools.com/electronics/friis.htm>

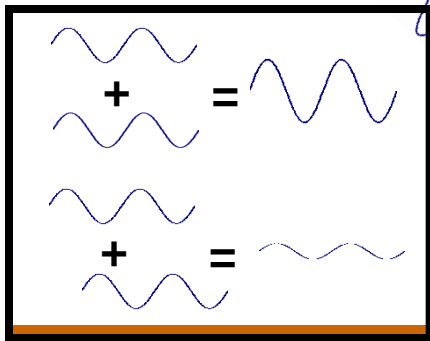
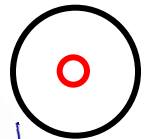
Propagation Effects

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Transmitting
Antenna



Receiving
Antenna

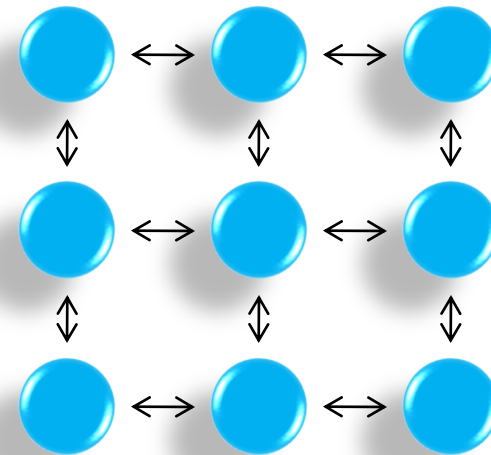
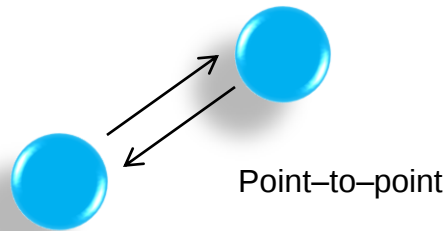


Source: TI

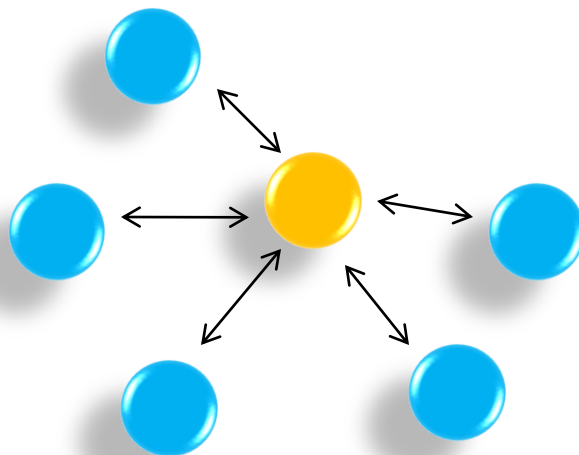
Protocol	Governing Body	Topology	Radio	Data Rate	Modulation	Security	Comment
6LoWPAN	IETF	Star	IEEE 802.15.4	250kbps	DSSS, FSK	IPsec	IPv6 Networking Over WPAN
ANT	Proprietary	Star Or Mesh	2.4GHz (Nordic Semi)	20kbps	GFSK	8-Byte Network Key (Unencrypted)	Frequency Adaptive, Isochronous TDMA
Bluetooth LE	Bluetooth SIG	Star	2.4GHz	1Mbps	FHSS, FSK	128-Bit AES	Body Area Networks
DASH7	ISO/IEC	Star	433MHz	28kbps	FSK or GFSK	Future Enhancement	Asynchronous Command-Response. Substantial DOD Investment
DigiMesh	Proprietary Digi International	Mesh	900MHz, 2.4GHz	250kbps	FHSS or DSSS	Future Enhancement	Time Synchronized CSMA
EnOcean	Proprietary EnOcean GmbH (120 Member Alliance)	Star	315MHz, 868MHz	120 kbps	ASK	Unique 32-bit product ID	Self-Powered Sensors and Switches
INSTEON	Proprietary SmartLabs Technology (400 member alliance)	Mesh	904MHz	38kbps	FSK	hidden 24-bit device ID, manual linking	Dual Media: RF + powerline. Legacy X10 Compatibility
ISA100.11a (aka SP100)	ANSI/ISA	Star Or Mesh	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES, Security Manager	Similar But Incompatible With WirelessHART. Also Transports Fieldbus, Modbus, Profibus
JenNet	Proprietary Jennic	Star	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES	Small Footprint Slack with Support for Large Self-forming Tree Networks
MiWi	Proprietary Microchip	Star Or Mesh	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES	Simpler MiWi P2P Version Has No Routing
ONE-NET	Open Source	Star Or Mesh	868/915 MHz	230kbps	FSK	XTEA-32	Wide Support From 8- and 16-Bit MCU Suppliers
SimpliciTI	Proprietary Texas Instruments	Star	315/433/868/915MHz, 2.4GHz	500kbps	Radio Dependent	XTEA-32	Range Extenders Add Up to 4 Hops
SNAP	Proprietary Synapse Wireless	Mesh	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES Version Available	Supports Bridging to TCP/IP Or ZigBee With Transparent RPC Calls
SynkroRF	Proprietary Freescale	Star	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES, Peer-To-Peer Key Exchange	Basis For RF4CE
WirelessHART	HART Communication Foundation	Star Or Mesh	IEEE 802.15.4 (2.4GHz only)	250kbps	DSSS, PSK	128-Bit AES, Security Manager	Channel Hopping TDMA. Compatible With Wired HART.
ZigBee	ZigBee Alliance	Star Or Mesh	IEEE 802.15.4	250kbps	DSSS, PSK	128-Bit AES, Global Key	Multi-Vendor Interoperability
ZigBee Pro	ZigBee Alliance	Star Or Mesh	IEEE 802.15.4	250kbps	DSSS, PSK	128-Bit AES, Peer-To-Peer Key Exchange	Adds Routing Options and Security
ZigBee RF4CE	ZigBee Alliance	Star	IEEE 802.15.4	250kbps	DSSS, PSK	128-Bit AES, Peer-To-Peer Key Exchange	Simplified ZigBee Without Mesh Capability For RF Remote Controls
Z-wave	Proprietary Zensys (160 Member Alliance)	Mesh	868/908 MHz	40kbps	FSK	32-Bit Network ID, Master Controlled Routing	Popular For Wireless Home Controls

Wireless Networks Topology 101

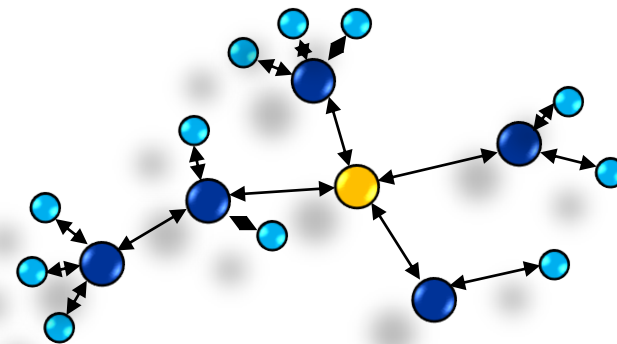
22



Mesh

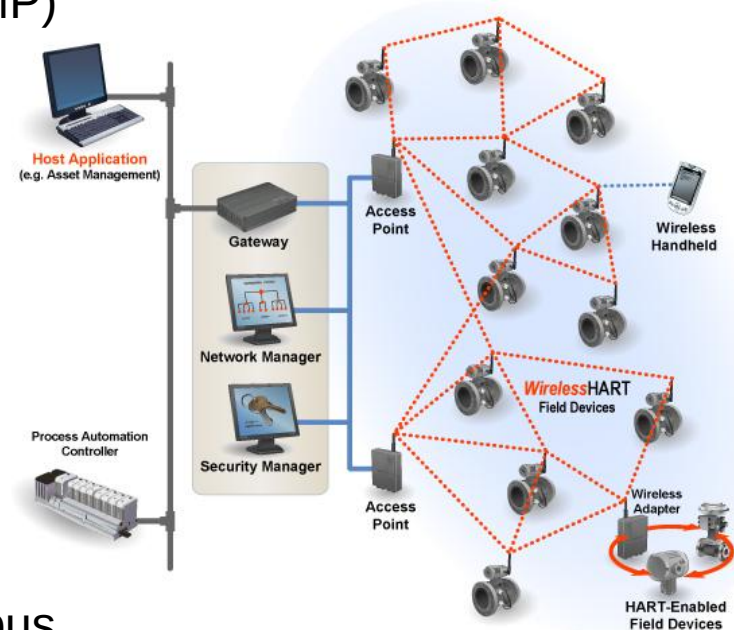


Star or Tree



Cluster-tree

- » Part of HART 7 specification
- » Highway Addressable Remote Transceiver
 - » FSK Data superimposed on 4 – 20mA current loop
- » Based on IEEE Std 802.15.4
- » Time Synchronized Mesh Protocol (TSMP)
 - » Invented by Dust Networks
 - » Time Synchronized
 - » Channel hopping
 - » Fully redundant mesh
 - » Path and frequency diversity
- » ISA100.11A
 - » Similar to WirelessHART
 - » Different MAC and APIs
 - » Transports Fieldbus, Modbus, Profibus



6LoWPAN



24

- » IPv6 over Low-Power wireless Area Networks
- » Low power RF + IPv6 = The Wireless Embedded Internet
- » 6LoWPAN is an adaptation header format
 - » IPv6 and UDP header compression
- » IP Packet fragmentation/reassembly
 - » 1280 byte IPv6 MTU
 - > 127 byte 802.15.4 frames

TCP/IP Protocol Stack

HTTP		RTP	
TCP	UDP	ICMP	
IP			
Ethernet MAC			
Ethernet PHY			

Application

Transport

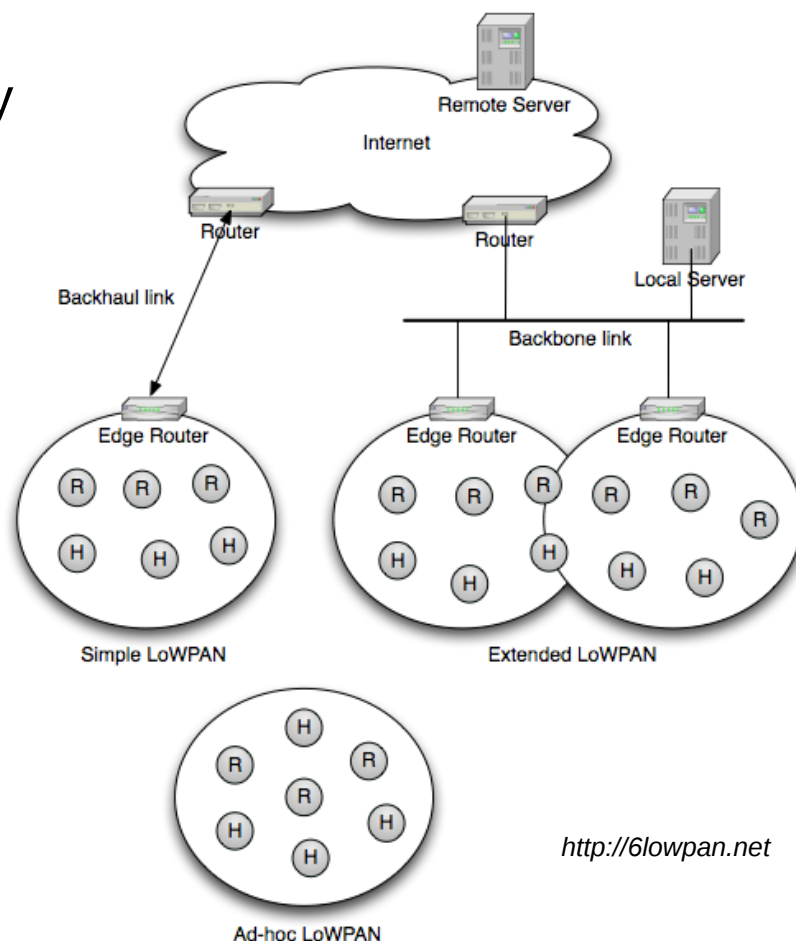
Network

Data Link

Physical

6LoWPAN Protocol Stack

Application	
UDP	ICMP
IPv6 with LoWPAN	
IEEE 802.15.4 MAC	
IEEE 802.15.4 PHY	

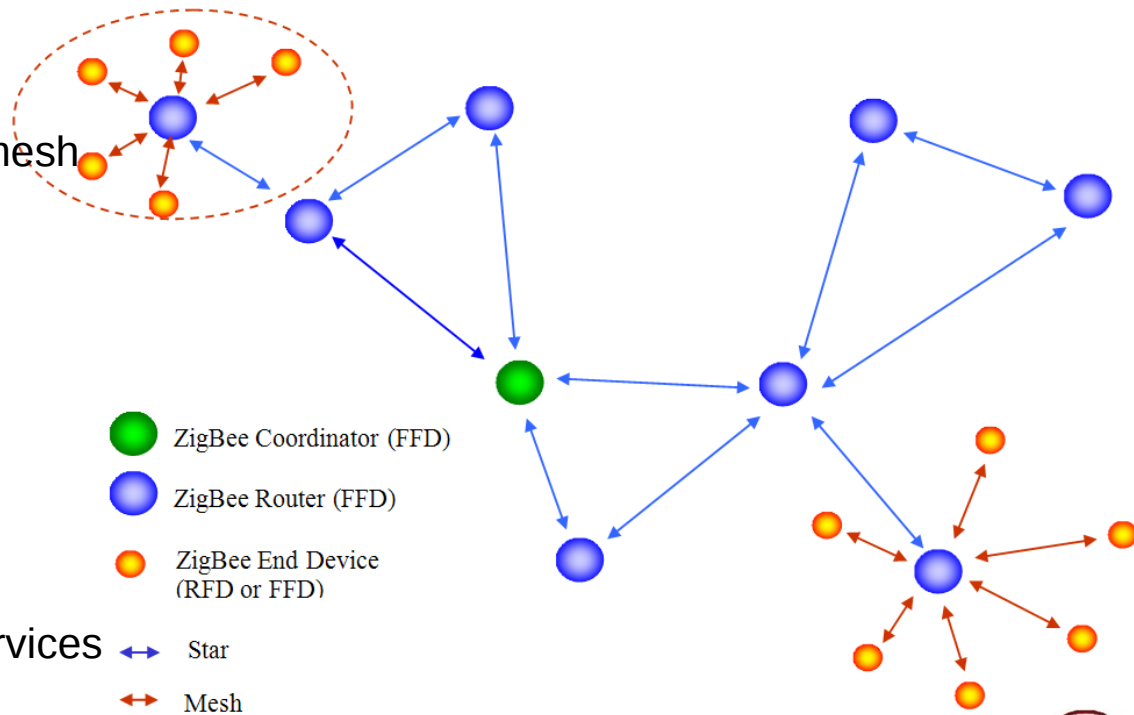


<http://6lowpan.net>

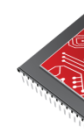
ZigBee



- » Protocol stack using IEEE Std 802.15.4 radio
- » 868/915 MHz, 2.45 GHz
- » Up to 16 channels
- » Data rates 20 - 250 kbps
- » Star (tree, cluster tree) or mesh
- » Self-forming, self-healing
- » Application profiles
 - » Smart energy
 - » Home automation
 - » Building automation
 - » Health care
 - » Remote control
 - » Telecommunication services
 - » Retail services
- » ZigBee RF4CE
- » ZigBee IP
- » ZigBee Green Power



ZigBee®
Certified product

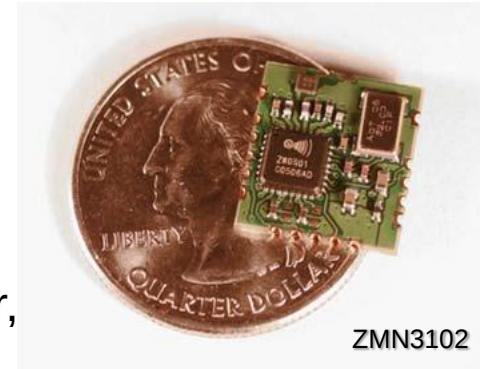


**DESIGN STRATEGIES
FOR ARM SYSTEMS**
An Avnet Design Summit

Z-Wave



- » Narrowband sub-GHz (868/915 MHz)
- » Up to 100kbps
- » Mesh network
- » Established wireless home controls
- » Proprietary to Zensys (Sigma Designs)
- » 160 member Alliance includes Cisco, Intel, Cooper, Intermatic, etc



Bluetooth

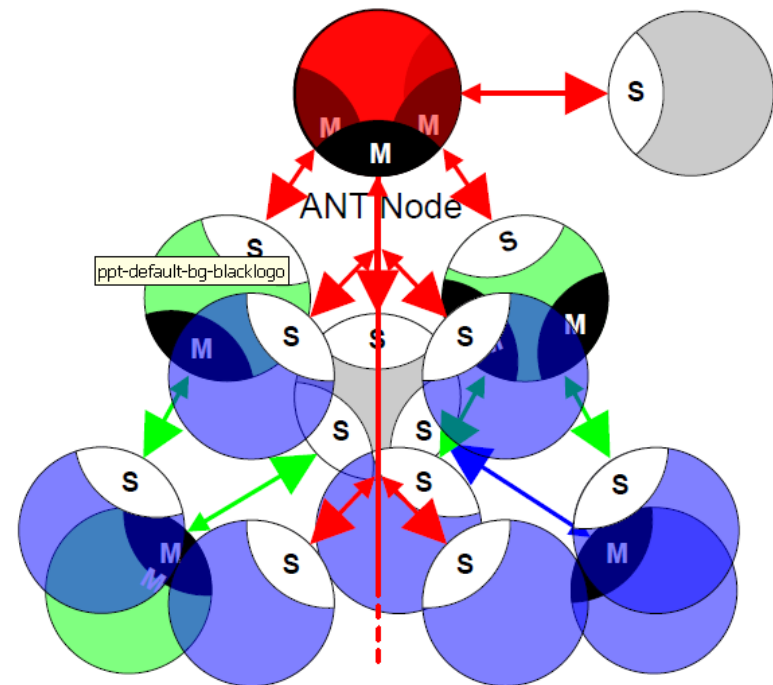


- » Classic Bluetooth
 - » 79 ch FHSS in 2.4GHz license free band
 - » Data rates up to 3Mbps (v 2.1)
 - » QoS for voice
 - » Star network with 7 slaves
 - » High latency
 - » Primarily Cable Replacement
 - » >100M devices deployed
- » Bluetooth Low Energy (BT 4.0)
 - » 40 ch FHSS in 2.4GHz band
 - » Interoperable with Classic, but not voice capable
 - » Low latency (~6ms), low power
 - » Data rate up to 1Mbps
 - » Body Area Networks, Sports & Fitness
- » Dual Mode ICs shipping now



Biorasis Inc.

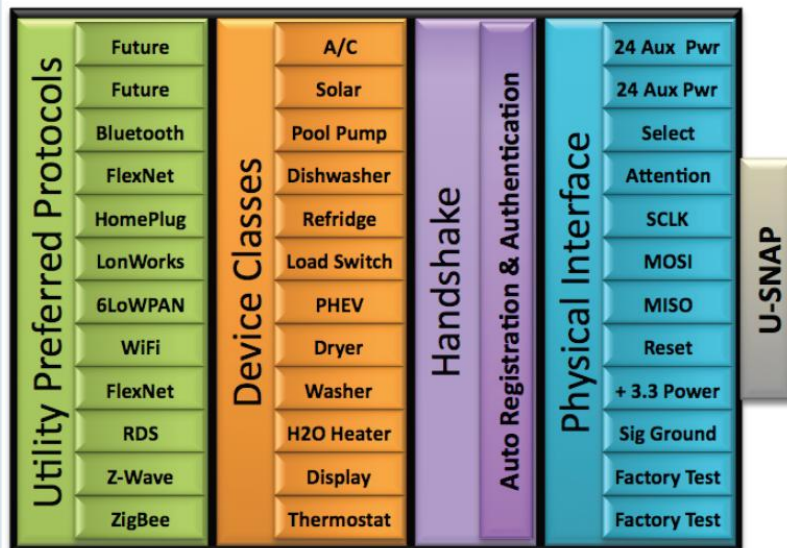
- » Narrowband 2.4GHz radio
- » TDMA (Frequency adaptive)
- » 125 channels, 1MHz wide
- » 20kbps data rate
- » Peer-to-peer, star or tree
- » Session based file system
- » Until now, exclusive on Nordic
 - » TI CC2570/1



U-SNAP



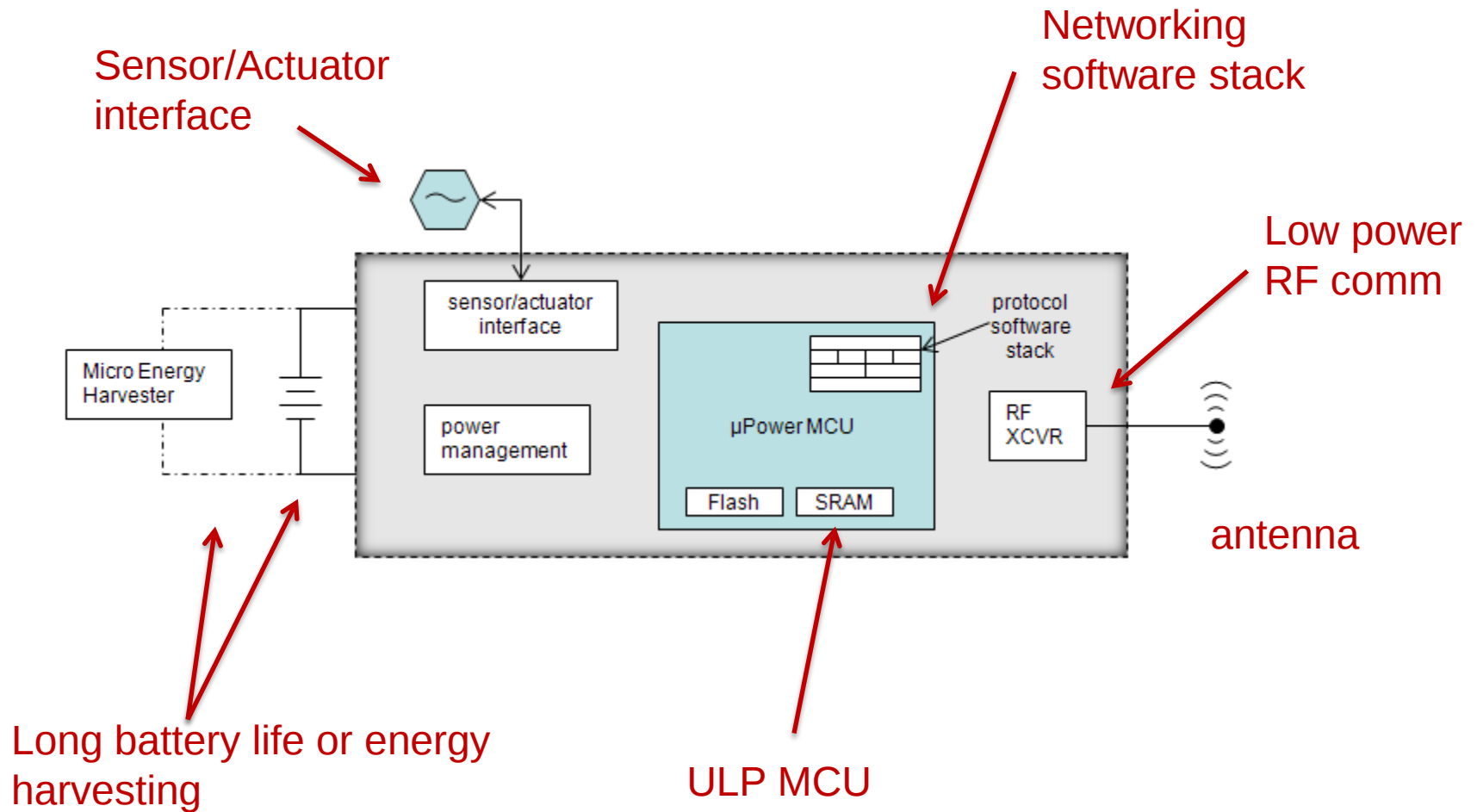
- » Protocol independent physical and serial interface standard
- » Enables any HAN (Home Area Network) standard, present and future, to use any vendor's Smart Meter as a gateway into the home
- » Avoids adding additional hardware in the Smart Meter.



- » Wireless
 - » Insteon
 - » DASH7
 - » io-homecontrol
 - » Wireless M-bus
 - » Proprietary – DigiMesh, SNAP, JenNet, PeakNet, SimpliciTI, FlexNet, MiWi, etc.
- » Wired:
 - » HomePlug
 - » LonWorks
 - » PLC

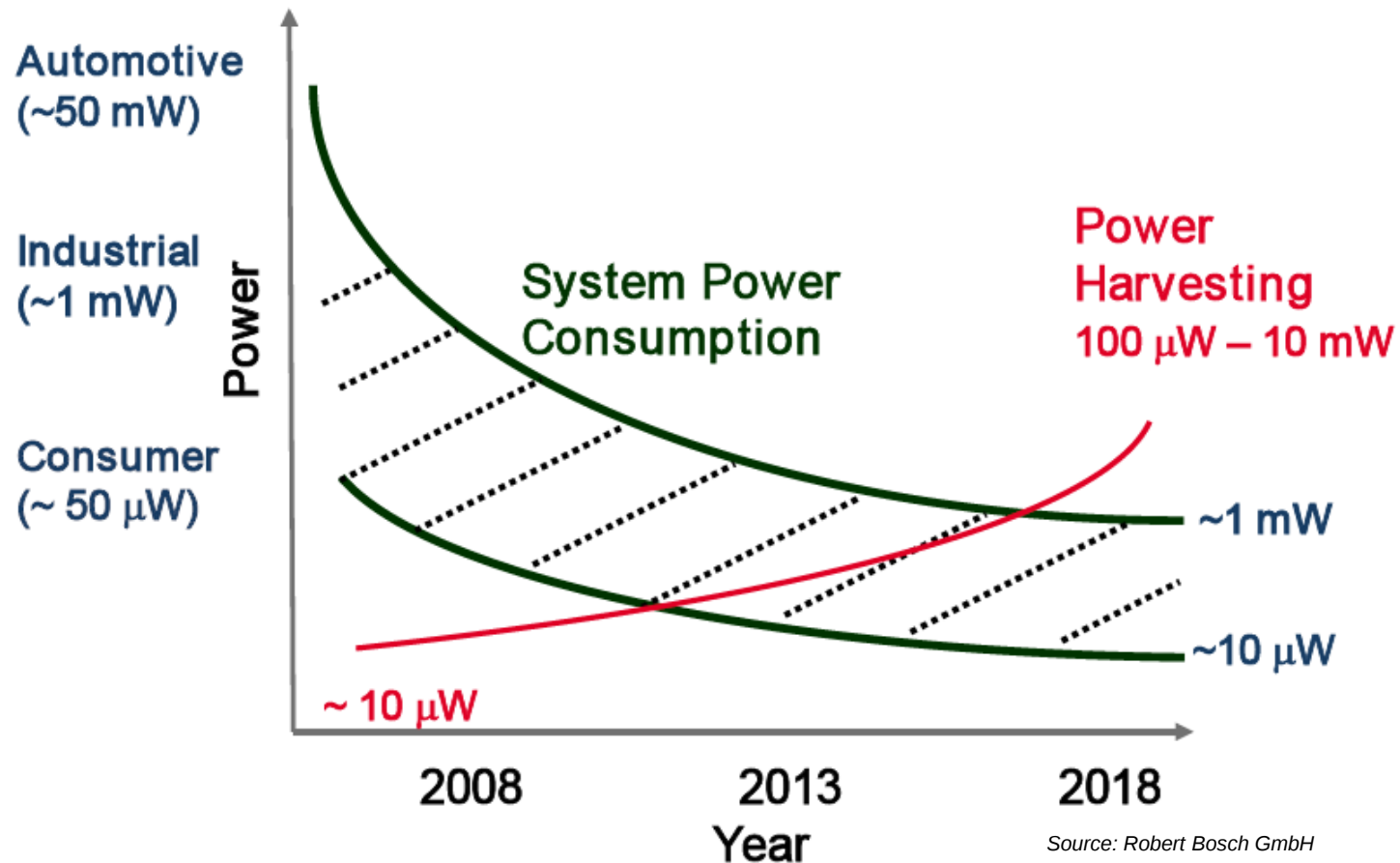
Components of a Wireless Sensor

31



ULP MCUs and Energy Harvesting

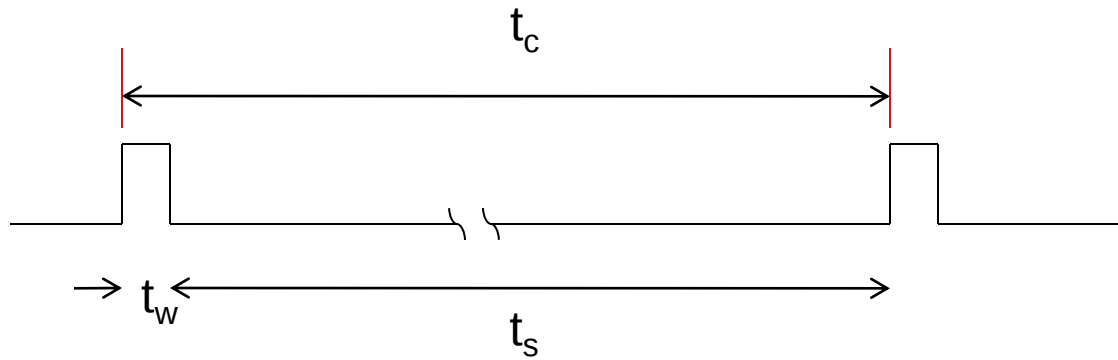
32



Managing Battery Life

33

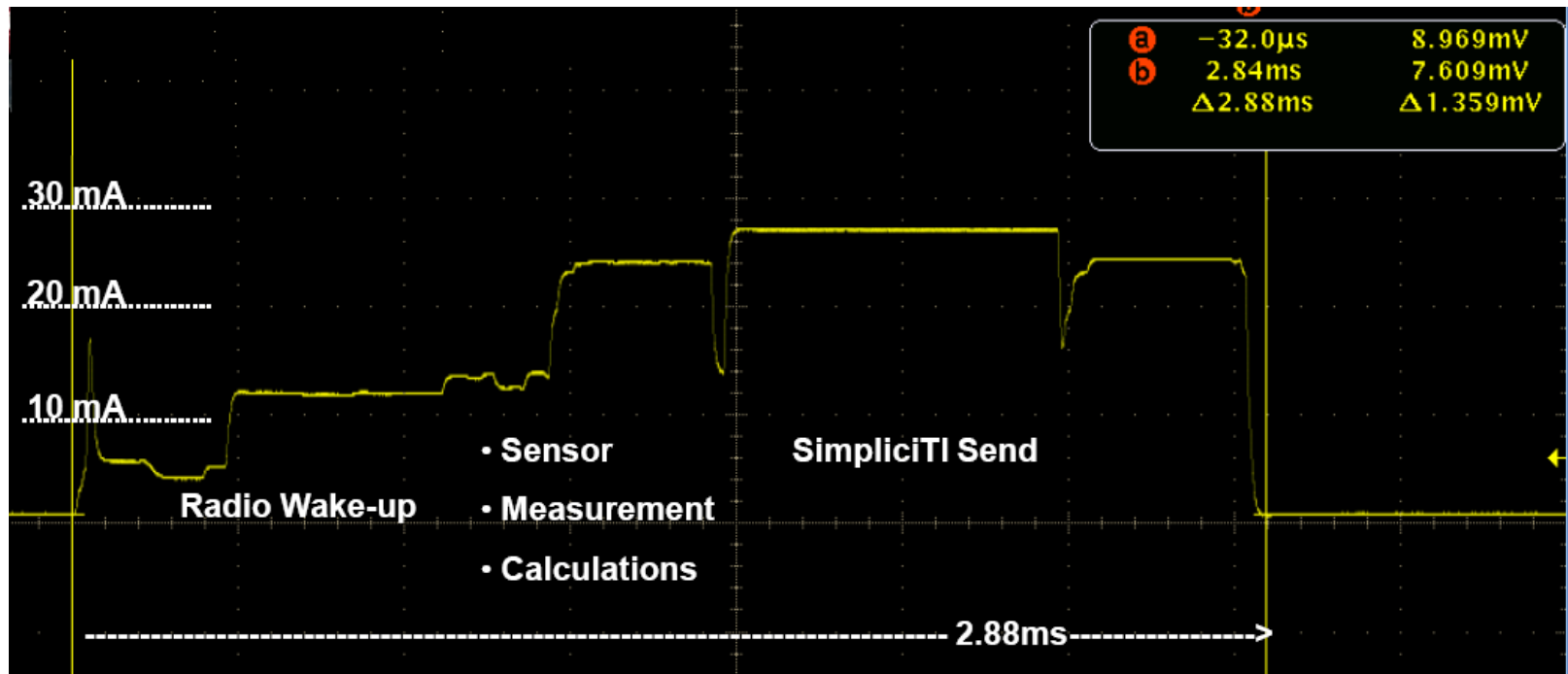
- » Duty cycle is critical for long battery life



$$P_{avg} = \frac{P_w t_w + P_s t_s}{t_c} \quad t_s \gg t_w$$

Power Profile Example (TI)

34

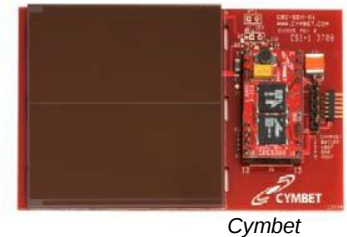
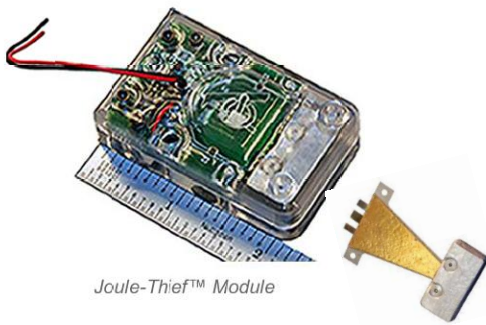
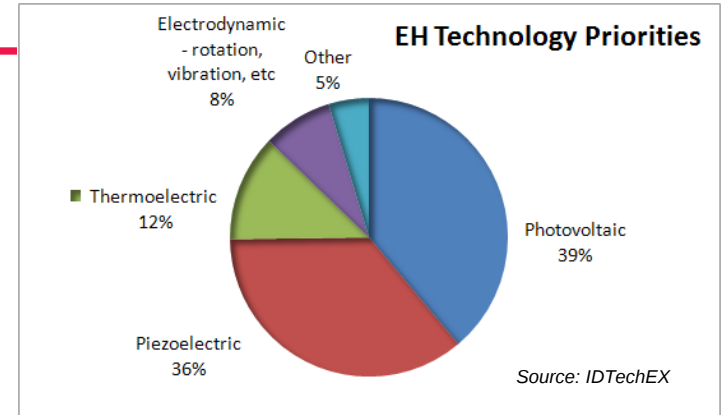


*18mA on average for 2.88ms / TX packet
11uA total average system @ TX packet /5s*

Energy Harvesting

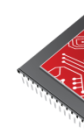
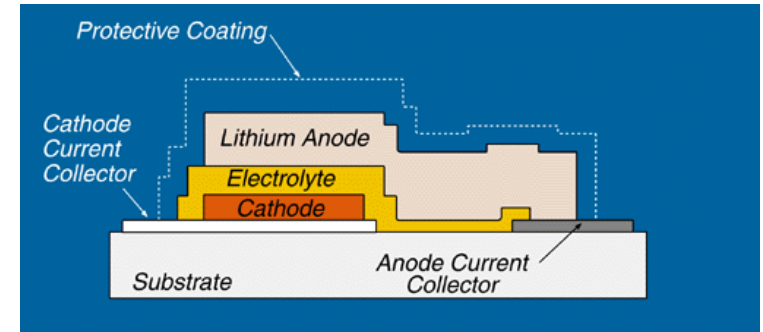
35

- » Ambient energy:
 - » Light – photovoltaic
 - » Vibration – piezoelectric effect or magnet/coil
 - » Heat – Peltier-Seebeck effect
 - » Mechanical motion
 - » RF
- » Zero maintenance sensors
 - » no batteries, no wiring



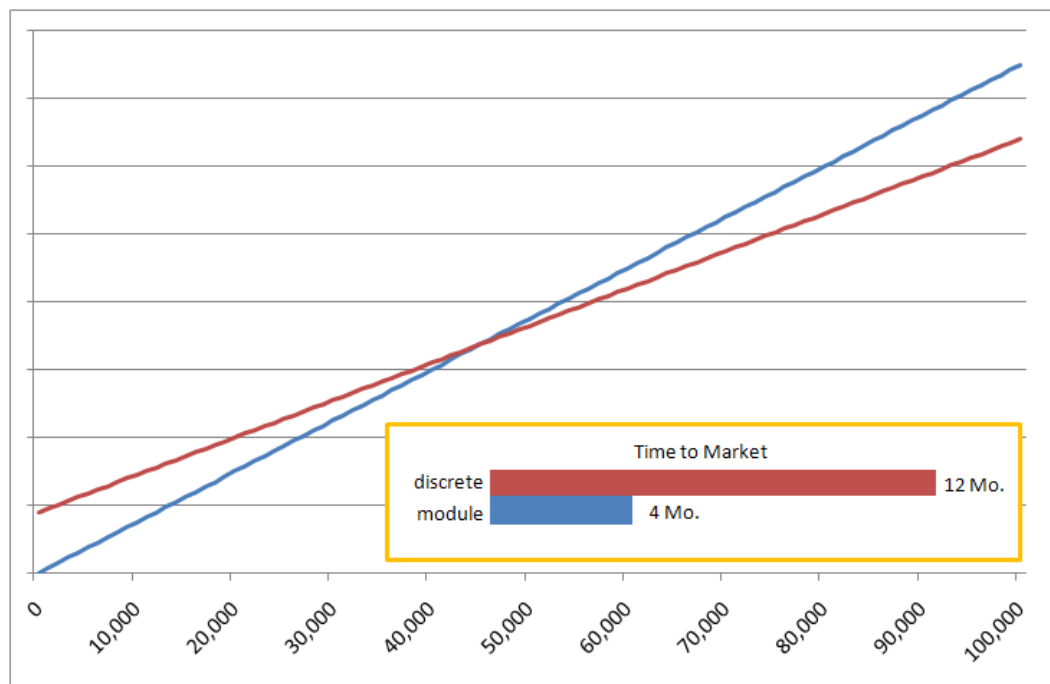
Thin Film Batteries

- » Solid State “chip battery”
- » Advantages
 - » No liquid/gel electrolyte
 - » Environmentally safe
 - » Accepts tiny charging current
 - » High discharge
 - » Fast recharge – 10 mins
 - » Low self-discharge
 - » Surface mount, tolerates solder reflow
- » Disadvantages
 - » Tiny capacity vs. coin cells
 - » Higher cost vs. coin cells



Make vs. Buy

37



Make

- RF Circuit Design & Layout
- Firmware
- Test & Debug
- *Re-spin?*
- Certification
- Multi-component BOM
- Fab & Test

Buy

- Pre-certified
- Assembled, tested, calibrated
- One part number
- Smallest size
- Short time-to-market

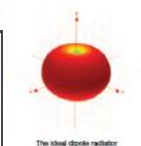
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- » RF Line Card
- » Antenna Guide
- » On The Web:
 - » www.em.avnet.com/rf
 - » www.em.avnet.com/SmartNetworks
- » Development Kits:
 - » www.AvnetExpress.com
- » Training & Events
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- » Local FAEs



Many common electronic devices rely on antennas to communicate wirelessly. Antennas are transducers that convert electromagnetic waves

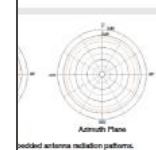
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The ideal dipole radiator

Antenna performance is typically graphed in separate antenna's directivity and side lobes point of field strength around of the



Antenna radiation patterns

Antenna has two conductors, a ground. Baluns are used to impedance transformation to the Earth's surface. Polarization

Antenna is the antenna.



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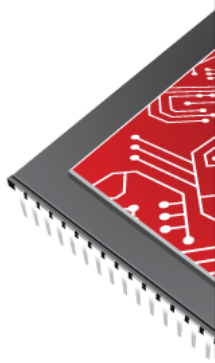
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Comments Welcome:

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